Climate Change & Waterborne Disease

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3.4 MILLION PEOPLE DIE EACH YEAR FROM A WATER RELATED DISEASE. THAT IS ALMOST THE ENTIRE CITY OF LOS ANGELES.

780 MILLION PEOPLE LACK ACCESS TO CLEAN WATER.

THAT’S MORE THAN 2½ TIMES THE UNITED STATES POPULATION.

Water.org
Water and Public Health

• Pathogens and waterborne disease
• 2 million deaths annually due to unsafe water, sanitation and hygiene
• 4% of the global disease burden could be prevented by improving water supply, sanitation, and hygiene
  – WHO 2013
“Whoever would study medicine aright must learn of the following subjects. First he must consider the effect of each of the seasons of the year and the differences between them. Secondly he must study the warm and the cold winds, both those which are common to every country and those peculiar to a particular locality....”

Hippocrates, “Airs, Waters, Places”, 400 bc
Pre 1850s
Miasma

e.g., 2008, ENSO-based cholera model (Pascual et al.)

1854 London
Waterborne Disease
Climate and Waterborne Disease

- Climate is one factor in overall risk from certain water (or foodborne) pathogens
  - Vulnerability
  - Resilience
  - Exposure
  - Physiology
  - Ecology
  - Geography
Until mid-century projected climate change will impact human health mainly by exacerbating health problems that already exist (very high confidence) …

Greater likelihood of injury, disease, and death due to more intense heat waves and fires (very high confidence); increased likelihood of under nutrition resulting from diminished food production in poor regions (high confidence); risks from lost work capacity and reduced labor productivity in vulnerable populations; and increased risk from food and water borne diseases (very high confidence) and vector-borne diseases (medium confidence) …

The most effective vulnerability reduction measures for health in the near-term are programs that implement and improve basic public health measures such as provision of clean water and sanitation, secure essential health care including vaccination and child health services, increase capacity for disaster preparedness and response, and alleviate poverty (very high confidence). …
How do climate and weather affect waterborne pathogens?
Climate Change Effects on Health

- Environmental Conditions
  - Precipitation
  - Heat
  - Extreme weather
  - Etc.
  - Geography
  - Baseline weather
  - Soil/dust
  - Vegetation
  - Local air pollution
  - Etc.

- Societal Infrastructure
  - Direct: floods, storms, heat, etc.
  - Indirect: Mediated through natural systems: allergens, disease vectors, etc.

- Public Health Capability and Adaptation
  - Warning systems
  - Socioeconomic status
  - Health and nutrition status
  - Primary healthcare
  - Etc.

- Economic and Social Disruption: malnutrition, refugees, etc.

- Health Impacts
  - Malnutrition
  - Drowning
  - Heart disease
  - Malaria
  - Etc.

WGII.AR5.Chapter11. 2014
Climate Change and Waterborne Disease

- Climate change scenarios relevant to waterborne disease include:
  - Rising temperature
  - Changes in hydrologic cycle
  - Change in frequency of ‘extreme events’
  - Sea level rise

- Can affect wide range of waterborne pathogens, especially those with an environmental reservoir
  - Indirect
3.2.1.4 Water quality

Higher water temperatures, increased precipitation intensity, and longer periods of low flows are projected to exacerbate many forms of water pollution, including sediments, nutrients, dissolved organic carbon, pathogens, pesticides, salt and thermal pollution. This will promote algal blooms (Hall et al., 2002; Kumagai et al., 2003), and increase the bacterial and fungal content (Environment Canada, 2001). This will, in turn, impact ecosystems, human health, and the reliability and operating costs of water systems. [WGII 3.ES]
Waterborne Pathogens

• Infrastructure-associated
  – Enteric pathogens
  – Sanitation
  – Hygiene

• Native
  – May be enteric or non-enteric
  – Part of aquatic ecosystems

Distinct Links to Climate and Adaptation
Pathways for Weather to Affect Health

Example = Diarrheal Disease

Distal Causes
- Temperature
- Humidity
- Precipitation
- Living conditions (water supply and sanitation)
- Food sources and hygiene practices

Proximal Causes
- Survival/replication of pathogens in the environment
- Contamination of water sources
- Contamination of food sources
- Rate of person to person contact

Infection Hazards
- Consumption of contaminated water
- Consumption of contaminated food
- Contact with infected persons

Health Outcome
- Incidence of mortality and morbidity attributable to diarrhea
- Vulnerability (e.g., age and nutrition)
Disease Trends with Climate and Weather

*Distal Causes – Infrastructure Related*

- Storms and flooding
  - Run off and microbial loading
  - Increased exposure expected
    - Drinking water
    - Recreational water
    - Incidental exposure
Frequency of Heavy Precipitation

The map to the left illustrates how heavy rains have become more frequent and intense across the United States over the past 50 years, with the greatest increases in very heavy precipitation in the Northeast and Midwest. The figure above shows further changes projected by 2090 (compared with the 1990s) in average amounts of light, moderate, and heavy precipitation in North America.

Source (both figures): Karl et al. (2009)

Karl et al. 2009
Storm events & waterborne disease

51% of outbreaks preceded by ppt >90th %-ile
68% of outbreaks preceded by ppt >80th %-ile
Storm Effects on Waterborne *Salmonella* in Georgia

13 serotypes and 89% of isolates in storm samples match human cases

Max 350 MPN L$^{-1}$

P = 0.007

Martin et al. In prep
Monthly mean rainfall and season as predictors of salmonellosis in Georgia

[Graph showing monthly mean rainfall and season variations over a study period from 1990 to 2016, with data points indicated by pink and yellow markers for case and predicted means, respectively.]
Climate, Disease and Water Infrastructure

Climate change is already affecting water utilities, according to a 2009 report from the National Association of Clean Water Agencies and the Association of Metropolitan Water Agencies, industry advocacy groups based in Washington, DC. A seemingly contradictory witches’ brew of more frequent and extreme storms, drought, and sea-level rise is beginning to stress some cities’ water infrastructure.


= Potential for Adaptation! (Trends may not equal risk)
Disease Trends with Climate and Weather

**Distal Causes – Naturally Occurring Pathogens**

- Many diseases are seasonal in nature, both enteric and naturally occurring
- Temperature tends to be a strong correlate for many pathogens with an environmental reservoir
  - *Salmonella*
  - *Campylobacter*
  - *Vibrio*
  - *Naegleria fowleri*
- Less options for infrastructure-based adaptation, more focus on evaluating future trends
*Naegleria fowleri* – emerging climate sensitive pathogen?
Naegleria *fowleri* – Ecology & Pathology

Although trophozoites are killed rapidly by refrigeration, cysts can survive for weeks to months at cold temperatures above freezing, although they appear to be sensitive to freezing. 

Naegleria *fowleri* grows best at higher temperatures up to 115°F (46°C). Although the amebae may not be able to grow well, *Naegleria fowleri* can still survive at higher temperatures for short periods of time. The trophozoites and cysts can survive from minutes to hours at 122-149°F (50-65°C) with the cysts being more resistant at these temperatures.
PAM Reports Associated with High Temperatures

Case-reports of Primary Amebic Meningoencephalitis by Month of Illness Onset and Probable Water Exposure: US, 1962-2012 (CDC)

Infection rates (0-8/yr) too low for statistical evaluation for association with temperature trends.
Rates are low – impact is high
At least 12 species can infect humans. In US, primary causes of disease:

- *V. parahaemolyticus*
- *V. vulnificus*
- *V. cholerae* (non O1)
- *V. alginolyticus*
Vibrio Transmission & Disease

Oyster & seafood consumption

Recreational exposure

CDC Emerging Infectious Diseases Volume 10, Number 8, August 2004
Vibrio Disease Burden

- Vibrio pathogens respond quickly to favorable temperatures
  - Among the fastest known doubling times
  - Populations expand rapidly as temperatures increase above 15°C
Vibrio Disease Burden

• Globally, Vibrio illness rates are rising
  – >115% since 1998 in the US
• Expansion related in part to changes in sea surface temperatures and changes in circulation
Seasonal Expansion in Illness

Figure 2. Nonfoodborne *Vibrio* infections (dark gray) and death (light gray) by month, United States, 1997–2006. Data were available for 706 (59%) of 1210 cases.

Martinez-Urtaza et al. 2010. Food REsearch International. Climate anomalies and the increasing risk of *Vibrio parahaemolyticus* and *Vibrio vulnificus* illnesses.
Range Expansion – Outbreak and Temperature Anomaly

Martinez-Urtaza et al. 2010. Food REsearch International. Climate anomalies and the increasing risk of *Vibrio parahaemolyticus* and *Vibrio vulnificus* illnesses
Ocean warming and spread of pathogenic Vibrios in the aquatic environment
L Vezzulli, RR Colwell, C Pruzzo - Microbial ecology, 2013 - Springer
Can threshold temperature projections help to understand risk?

1990 Baseline

1990 Sea Surface Temperature (°C)
Baseline
August
- >25.0
- 20.1 - 25.0
- 15.0 - 20.0
- 10.0 - 14.9
- <10.0
Can threshold temperature projections help to understand risk?

Range expansion?
Can threshold temperature projections help to understand risk?

Seasonal expansion?
Extreme Events and *Vibrio*

March 9, 2004

August 31, 2005

New Orleans

Average *Vibrio* infections in September along Gulf Coast: **14**

Average *Vibrio* infections in 1 week (2 states) following Katrina: **22**
# Direction and Magnitude of Climate Change Health Impacts

<table>
<thead>
<tr>
<th>Negative impact</th>
<th>Positive impact</th>
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</thead>
<tbody>
<tr>
<td><strong>Very high confidence</strong></td>
<td>2014, high confidence</td>
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<tr>
<td>Malaria: contraction and expansion, changes in transmission season</td>
<td></td>
</tr>
<tr>
<td><strong>High confidence</strong></td>
<td></td>
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<td>Increase in malnutrition</td>
<td></td>
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<tr>
<td>Increase in the number of people suffering from deaths, disease and injuries from extreme weather events</td>
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<tr>
<td>Increase in the frequency of cardio-respiratory diseases from changes in air quality</td>
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<td>Change in the range of infectious disease vectors</td>
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<td>Reduction of cold-related deaths</td>
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<tr>
<td><strong>Medium confidence</strong></td>
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<tr>
<td>Increase in the burden of diarrhoeal diseases</td>
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IPCC 2007. Working Group II
Snap shot of Weather-Associated Waterborne Disease in US

- Heavy precipitation. >2,000 ill (2000)
- Hurricane/Flooding. Flooded hog farms and 2 x treatment for AGI (1999)
- Hurricane/Flooding. Storm surge and *Vibrio* infections (2005)
- Warming temperatures. Expanding season for *Vibrio* infections (ongoing)
Climate and Waterborne Disease

- Climate projections for increased warming, increased extreme events and sea level rise indicate increased risk for waterborne disease.
- Climate is only one component contributing to risk.

- Understanding the mechanisms that drive potential changes in pathogen ecology or human exposure patterns will be a critical part of successful adaptation.
Thanks!
### North America

<table>
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<tr>
<th>Key risk</th>
<th>Adaptation issues &amp; prospects</th>
<th>Climatic drivers</th>
<th>Timeframe</th>
<th>Risk &amp; potential for adaptation</th>
</tr>
</thead>
</table>
| Urban floods in riverine and coastal areas, inducing property and infrastructure damage; supply chain, ecosystem, and social system disruption; public health impacts; and water quality impairment due to sea-level rise, extreme precipitation, and cyclones *(high confidence)* | • Implementing management of urban drainage is expensive and disruptive to urban areas.  
• Low-regret strategies with co-benefits include less impervious surfaces leading to more groundwater recharge, green infrastructure, and rooftop gardens.  
• Sea-level rise increases water elevations in coastal outfalls, which impedes drainage. In many cases, older rainfall design standards are being used that need to be updated to reflect current climate conditions.  
• Conservation of wetlands, including mangroves, and land-use planning strategies can reduce the intensity of flood events. | | Present | Very low | Medium | Very high |
| | | | Near-term (2030-2040) | | | |
| | | | Long-term (2080-2100) *2°C* | | | |
| | | | Long-term (2080-2100) *4°C* | | | |
Number of Case-reports of Primary Amebic Meningoencephalitis by Year: United States, 1962-2012